Advances in the development of a new force-feedback tactile device

Frédéric Giraud, Mélisande Biet, Betty Lemaire-Semail

Advances in the development of a new force-feedback tactile device

Frédéric Giraud, Mélisande Biet, Betty Lemaire-Semail
Laboratoire d'Electrotechnique et d'Electronique de Puissance de Lille
IRCICA, 50 Rue Halley, 59655 Villeneuve d'Ascq cédex

Abstract:
This article presents the design of a new tactile stimulator which is able to make a user feeling the sensation that he's touching a programmable textured surface. In a first section, the principle of the interaction between the device and the finger is presented. Then, we describe the design of the stimulator which is made up with a layer of piezo-ceramic bonded on a copper plate. Finely, we show the control electronic. Experimental runs are presented.

Keywords: Piezo-electric, tactile stimulator

Introduction

Past few years have seen tactile devices emerging in our every-day world. They become very useful for setting a record on a music player which are smaller and smaller, and touching a screen for communicating with a computer is no longer strange. However, we could expect more from those devices. In fact, by providing force feedback on its finger pulp, a user can retrieve information from its sense of touch. This is of course very useful for blind people, but for everyone, this is the opportunity to manage without a screen, or to really feel a texture displayed in a screen.
Designing a force-feedback tactile device is not straightforward. Some devices are based on pins array which outline a programmed surface. The number of pins is then a trade-off between accuracy and bulk size. Other devices output the same stimulation over the whole finger pulp, but with stimuli synchronized on the position of the finger.
In the paper, we present the design of a tactile stimulator which presented good performances for simulating finely textured surfaces. It is based on friction reduction between the finger and the touched device, and allows a free movement of the finger as well as a large explored surface.
In a first section, a modelling of the interaction between the finger and the surface is proposed, leading to the key requirements for the device. Then, the device is designed; the solution presented helps to achieve good tactile stimulations with a thin device. Finally, the power and control electronic are described.

Modelling of the interaction.

[1] shows that if a plate vibrates opposite an other, an overpressure appears between them. This effect, called "squeeze film air bearing" or "squeeze effect" reduces friction between the two plates. This effect may occur if the squeeze number σ is sufficiently big and the following condition is assumed to be necessary:

$$\sigma = \frac{12\,\eta\,\omega_0\, l}{p_0 h^2} \geq 10 \qquad (1)$$

Where

η	Air's viscosity
ω_0	Vibration's frequency
l	Length of the vibrating plate
p_0	Nominal pressure
h	Nominal air gap

In [2] this "squeeze effect" is used in order to produce a tactile feedback. To achieve that, a plate is vibrating at several kilohertz. When touching this plate, a finger traps air in the gap leading to the squeeze film. By modifying the vibration amplitude, the plate – on which sand paper is glued – is felt more or less rough.
In this case, (1) has to be revised in order to take into account the effect of the epidermal ridges which increases h_0, and thus reduce σ for the same operating conditions. To achieve that, epidermal ridges are supposed to have a sinusoidal shape along the fingertip. Moreover, the problem is reduced to a 2D problem, meaning that we do not take into account the bounding effect in the orthogonal direction. Figure 1 shows the modelling of the interaction under vibrations while average figures for the epidermal ridges from biometric measurements are summarized as follows:

h_e=100µm	Ridges' height
L=350µm	Ridges width
l_0=1cm	Pulp width

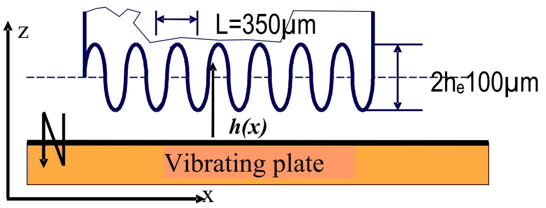

***Figure 1:** Modelling of the interaction between a finger and a plate*

If we call h(x) the space in the air gap, we can see that h(x) depends on:

- the epidermal ridges. We call $h_1(x)$ this value;
- time because the plate vibrates. We call $h_2(t)$ this vibration;
- plate's roughness which create a threshold between finger's surface and the plate. We call hr this threshold.

Accounting for those notations, we can write down:

$$h_1 = h_e\left(1+\cos\left(2\pi\frac{x}{L}\right)\right) \qquad (2)$$

$$h_2 = h_{vib}\left(1+\cos(\omega_0 t)\right) \qquad (3)$$

$$h(x,t) = h_r + h_{vib}\left(1+\cos(\omega_0 t)\right) + h_e\left(1+\cos\left(2\pi\frac{x}{L}\right)\right) \qquad (4)$$

In order to simplify the calculation, we are now introducing reduced variables:

$h_0 = (h_r + h_{vib})$, $H = \dfrac{h}{h_0 + h_e}$, $X = \dfrac{x}{L}$, $T = \omega_0 t$, $\varepsilon = \dfrac{h_{vib}}{h_0 + h_e}$ to finally obtain:

$$H = 1 + \varepsilon\cos(T) + \delta\cos(X) \qquad (5)$$

It is now possible to calculate the overpressure in the space between the plate and the finger. This study is based on work of [1]. Reynolds' equation is written:

$$\nabla\left(H^3 P^{1/3}\nabla P\right) = \sigma\frac{\partial\left(P^{1/n}H\right)}{\partial T} \qquad (6)$$

P is the normalized pressure (P=p/p0) and n=1. This leads to a new definition of the squeeze number:

$$\sigma = \frac{12\eta\,\omega_0 l_0}{p_0\left(h_0+h_e\right)^2} \qquad (7)$$

And the overpressure is given by:

$$P = \frac{1+\delta\cos(kX)}{1+\delta\cos\left(\frac{k}{2}\right)}\,\frac{\sqrt{\left(1+\delta\cos\left(\frac{k}{2}\right)\right)^2+\frac{3}{2}\varepsilon^2}}{\left(1+\varepsilon\cos(T)+\delta\cos(kX)\right)} \qquad (8)$$

From (7) and (8), we can calculate the guidelines for the design of a tactile stimulator. First, (8) is used to know which vibrating frequency is required for proper squeeze operation. We depicted in figure 2 the value of σ as a function of the vibrating frequency f_0 ($\omega_0 = 2\pi f_0$).

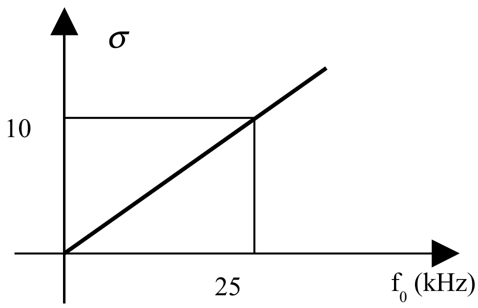

***Figure 2:** evolution of the squeeze number as a function of the vibrating frequency*

So, in order to achieve good "squeeze film air bearing" at least 25khz is required.
Then (8) is used to calculate the average overpressure over time appearing under the finger pulp. Results are presented in figure 3. In this figure, we represented the epidermal ridges and their simulated sinusoidal shape, and the overpressure.

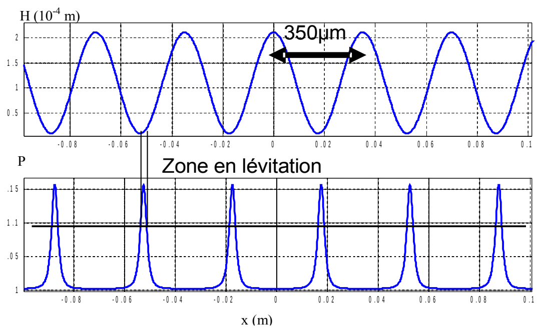

***Figure 3:** Calculated overpressure @ vibration of 1µm*

This overpressure depends on the location under the finger pulp: the zone under an epidermal ridge create much more overpressure than zones between two ridges. Of course, the overpressure is very low. However, they are in the same order of the contact pressure when touching a soft surface – a tissue for example. When the calculated overpressure is higher than the contact pressure, the the finger levitate at this point. Of course, this is not really the case, because the skin is not stiff enough to keep in the same shape. We can now integrate all over the finger pulp to deduce the average overpressure as a function of the vibrating amplitude depicted in figure 4. This value can be compared to the contact pressure which is equal to 0.1 bar in normal case.

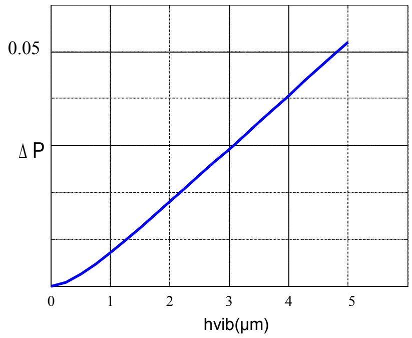

Figure 4: Calculated over pressure as a function of hvib

Thus, in order to create an overpressure equal to ¼ of the contact pressure, a vibrating amplitude of about 2.5µm is enough. This gives us a second requirement for the design of the tactile stimulator.

Design of the stimulator

Ergonomic studies have shown that space requirement for a free motion of the finger pulp on the device should be at least a 80mmx50mm rectangle. It should be made up with a vibrating plate at at least 25kH and 2.5µm of vibration amplitude. First set-up were using a langevin transducer to create the vibration of the plate. However, this was leading to a bulk size not compatible with laptop space requirements. This is why, instead of using a vibrating plate just moving up and down, we are using a standing wave which propagates at the plate's surface.

Of course, this decreases the squeeze effect, but we have shown that good tactile stimulation still remains. The final device is thus made up with a copper plate on which small piezoelectric elements are bonded in order to create the vibration. Figure 5 depicts the final device, the wave and the piezo ceramics used. We present the bottom view of the device(ceramic side) which is not actually touched by the user.

Dimension of the device has to be chosen so as to fulfil design requirements presented in the previous section. In fact, we must define which wavelength λ will propagate in the plate[4].

On the one hand, a large wavelength allows large vibration amplitude, but leads to low resonant frequency. This is why, an optimization process helps to find a good value for λ. First, we have plotted figure 6 the resonant frequency of a plate with several wavelength. In order to fulfil f_0>25kHz, this study shows that λ <28mm.

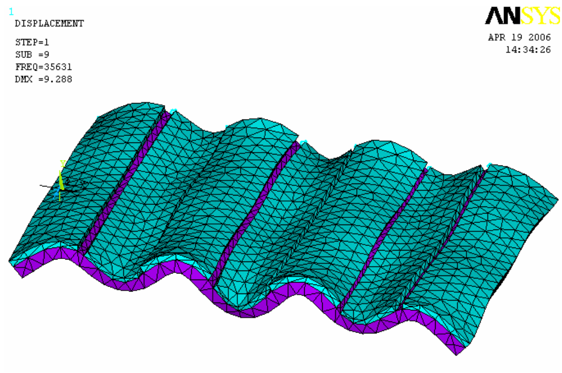

Figure 5: Simulation results of the tactile device.

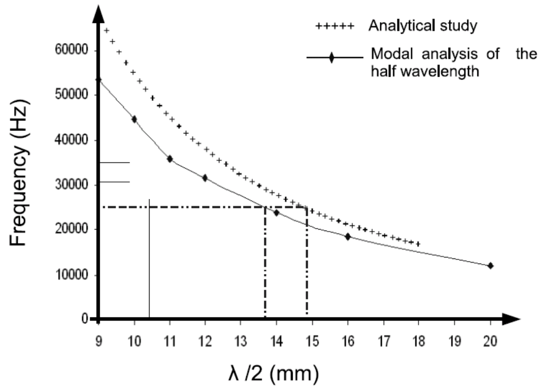

Figure 6: Evolution of the resonant frequency of the tactile plate as a function of the wavelength

Moreover, [3] advises to optimize the static deflection of a wavelength in order to optimize *in fine* dynamic deflection. This deflection is depicted in figure 7.

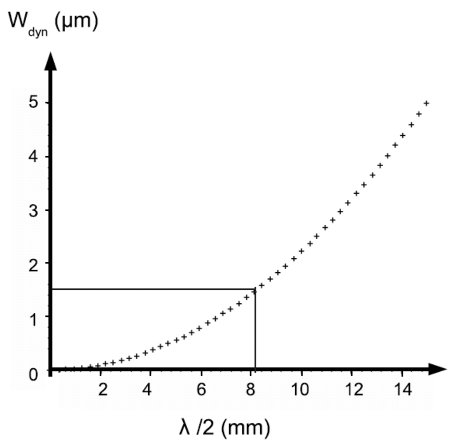

Figure 7: Analytical dynamic deflection as a function of the wavelength.

In order to reach a dynamic vibration of 2.5µm leads to λ >16mm. So, the wavelength should be $16mm < \lambda < 28mm$. Finally, we reached a device with 1.5µm of dynamic deflection and 30.5kHz of working frequency.

Application

The tactile stimulator (figure 8) is included in a test set up which is made up with a a resonant DC to AC converter which is adapted to the electrical supply of the piezo elements. In order to create the sensation of touching a finely textured surface, the device is powered on and off as a function of the position of the fingertip on the plate. To achieve that, a motion capture program based on a Philips SPC1300NC camera and a Windows/XP computer measures on real time the location of the fingertip on the plate. This position is sent through the RS232 port to a DSP board (EzDSP2808 evaluation board) which in turn controls the power supply of the tactile stimulator.

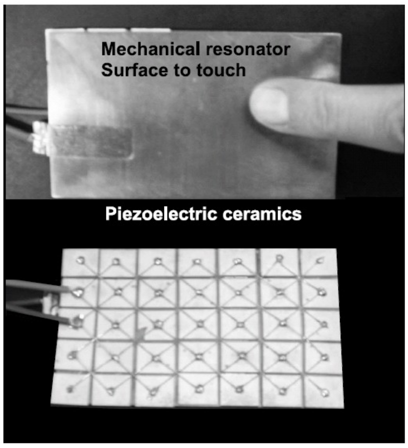

Figure 8: The designed tactile stimulator

In order to test accuracy with which the device is able to simulate grating with different spatial period, we asked people to discriminate a spatial period from an other[5]. We asked to compare 4 nominal spatial periods of 0.25cm, 0.35cm, 0.5cm and 1cm, and variations of +/- 25% of each spatial period. It appears that the weber's fraction found is closed to what is found when touching real gratings. This experience, done with 8 subject realizing 512 tests, demonstrates that the device is able to simulate

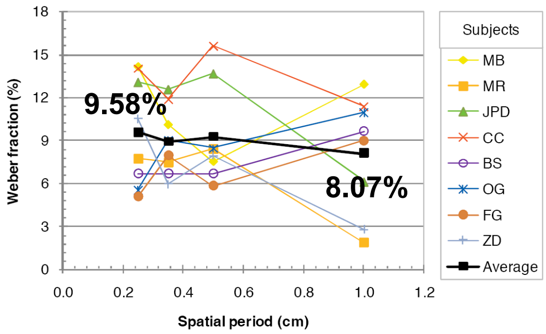

Figure 9: Weber's fraction as a function of the spatial period

finely textures surfaces.

Conclusion

This paper shows a new tactile device based on friction reduction between a plate and the finger tip. It allows a free motion of the finger and requires no moving part. It uses the “squeeze film effect” to produce friction reduction.

First, we presented the required conditions for being able to create this effect during tactile tasks. We concluded on a vibrating frequency of 25kHz for 2.5µm of vibrating amplitude.

Then we designed a transducer which fulfil those requirements. However, in purpose of size reduction, the whole plate is not vibrating up and down only, but we propagate a standing wave on its surface. A set of piezoelectric elements are bonded on the plate to generate the vibration.

At the end, the device is included in a control loop which switch on and off the device as a function of the position of the finger on the device in order to create the illusion that the user is touching a textured surface.

Further work should enhance the simulation by modifying the shape of the induced stimuli. Variable friction should be created by changing the vibration amplitude. Moreover, the interaction allows the propagation of vibration on a transparent substrate. This is a good point for designing new devices which induces tactile feedback as well as visual feedback.

Acknowledgement

This work has been carried out within the framework of INRIA Alcove project and is supported by IRCICA (Institut de recherche sur les composants logiciels et matériels pour l'information et la communication avancée)

References

[1] M. Wiesendanger Squeeze Film Air Bearing using Piezo Electric Elements,, PhDThesis of EPFLausanne, n°2336, 2001

[2] T.Watanabe, S.Fukui, A method for controlling tactile sensation of surface roughness using ultrasonic vibration, IEEE Int. Conf. on Robotics and Automation, pp. 1134–1139, (1995)

[3] V.Monturet,B.Nogarede, Optimal dimensioning of a piezoelectric bimorph actuator The European Physical Journal - Applied Physics, vol. 17, pp. 107–118, (2002)

[4] M.Biet, F.Giraud, B. Lemaire-Semail Squeeze Film effect for the design of a tactile plate,, IEEE Transactions on Ultrasonic Ferroeclectricity and Frequency Control, December 2007

[5] M.Biet, G.Casiez, F.Giraud, B.Lemaire-Semail Discrimination of Virtual Square Gratings by Dynamic Touch on Friction Based Tactile Displays, The 16th Haptics Symposium, March 13 2008, Reno, USA.